Silvicultural Alternatives for the Management of Unstable Sites in the Queen Charlotte Islands: A Literature Review and Recommendations

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FISH/FORESTRY INTERACTION PROGRAM

This study was undertaken as part of the Fish/Forestry Interaction Program, a multidisciplinary research study initiated in 1981. The program was started following a series of major winter storms in 1978 that triggered landslides over much of the Queen Charlotte Island forest land base. Originating on steep slopes, many slides deposited tonnes of debris in streams and on valley flats. The events raised private and public concerns over logging practices on the islands and prompted the establishment of the 5 year program. Overall objectives of FFIP were:

- to study the extent and severity of mass wasting and to assess its impacts on fish habitat and forest sites.
- to investigate the feasibility of rehabilitating stream and forest sites damaged by landslides.
- to assess alternative silvicultural treatments for maintaining and improving slope stability.
- to investigate the feasibility and success of using alternative logging methods, including skylines, helicopters, and by logging planning, to reduce logging-related failures.

The program is jointly funded by direct appropriations from the Canada Department of Fisheries and Oceans, the B.C. Ministry of Forests (Research Branch), and the B.C. Ministry of Environment (Fisheries Branch). Participating agencies include the Canadian Forestry Service (Pacific Forestry Centre) and the Forest Engineering Research Institute of Canada (FERIC), Vancouver, B.C.

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For information about the program contact Ministry of Forests, Research Branch, 1450 Government Street, Victoria, B.C. V8W 3E7.

Silvicultural Alternatives for the Management of Unstable Sites in the Queen Charlotte Islands: A Literature Review and Recommendations

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ABSTRACT

Forest cover plays an important role in modifying the severity and frequency of natural soil mass wasting. Removal of the forest cover through forest harvesting and the associated engineering operations can alter natural processes and aggravate inherent instability. In the Queen Charlotte Islands, steep slopes, finely textured soils, frequent seismic activity, heavy precipitation, shallow rooting tree species, and high winds predispose the area to a high natural level of mass wasting.

This preliminary appraisal reviews current silvicultural operations in the Islands and proposes alternatives. Traditional silvicultural systems are described and constraints imposed by the local conditions identified. Naturally occurring forests on the Queen Charlotte Islands are compared to projected managed forests that will replace them, and successional processes and their influence on mass wasting events are discussed. The report concludes by noting several research opportunities in the study of silviculture and mass wasting.

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1 INTRODUCTION

The Fish/Forestry Interaction Program (FFIP) is designed to find ways of reducing the impact of forestry-related mass wasting on fish habitat in the Queen Charlotte Islands (Poulin 1984). The silvicultural component of FFIP has the following objectives:

- to identify silvicultural alternatives for the management of unstable sites that pose a hazard to fish habitat and forest plantations on the Queen Charlotte Islands.
- to identify silvicultural research needs related to mass wasting on the Queen Charlottes Islands.

The Queen Charlotte Islands and adjacent areas of the Pacific Northwest are well described in the literature (Calder and Taylor 1968; Sutherland Brown 1968). Forest surveys (Phillips 1938), supply projections (B.C. Ministry of Forests 1982), ecological descriptions,[1] and provisional silvicultural prescriptions based on ecosystem units[2] have all been carried out in the region.

As well, the influence of harvesting and associated engineering practices on mass wasting has been well documented in the Pacific Northwest (Alley and Thomson 1978; Wilford and Schwab 1982; Schwab 1983; Lindeburgh et al. 1984; Sidle et al. 1985); and on the Queen Charlotte Islands slope stability hazard mapping at a scale of 1:20 000 has been undertaken for all forest development areas (Lindeburgh et al. 1984).

Silvicultural characteristics of the native species and their ecological relationships, genetic variability, and interaction with their associates are also well documented (Day 1957; Ruth 1958; Henman 1963; Ruth 1964;

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[1]Banner, A., J. Pojar, and R. Trowbridge. 1983. Ecosystem Classification of the Coastal Western Hemlock Zone, Queen Charlotte Islands Subzone (CWHg), Prince Rupert Forest Region, British Columbia. B.C. Min. For., Smithers, B.C., Unpubl. manuscript. 255p.

[2]Geisler, B.M. 1982. Silvicultural prescriptions for the CWHg, Queen Charlotte Islands, B.C. Min. of For., Smithers, B.C. Unpubl. manuscript. 23p.

Burley 1965; Kramer 1966; Lines and Mitchell 1966; Fraser and Gardiner 1967; Hamilton 1969; Eis 1973; Ford and Deans 1977; O'Driscoll 1977; Cochrane and Ford 1978; Ruth and Harris 1979).

This report discusses the silvicultural differences between natural forests and their man-made counterparts; reviews classical silvicultural systems and identifies constraints on their application in the Queen Charlotte Islands; and discusses the merits and problems of current silvicultural practices. Options available to forest managers are briefly outlined. The report ends with an outline and discussion of silvicultural research requirements related to mass wasting.

2 SILVICULTURE

Silviculture is the science that integrates physical and biological knowledge to establish and grow forests for specified goods and services. The silviculturist, in attempting to fulfill management directives, has developed many techniques to meet specific situations.

"Silvicultural system" may be defined as "a process, following accepted silvicultural principles, whereby the crops constituting forests are tended, harvested and replaced, resulting in the production of a distinctive form" (Daniel et al. 1979). Silvicultural systems are classified by cutting method practised, and range from total removal (i.e., clearcutting) to minimal disturbance, where individual trees are selected for removal according to either diameter limit or crown position in the canopy (i.e., selection).

Choice and application of a particular system reflect management objectives, economic considerations, expertise available to carry out management directives at field level, and constraints imposed by the physical and biological systems under consideration. The choice is, more often than not, a compromise, and falls short of the theoretical optimum. When alternatives are viewed, practical considerations dominate management decisions, and the resulting trade-offs rarely satisfy one party completely.

Silvicultural management in the Queen Charlotte Islands is dominated by practical decisions -- mainly economic -- and is complicated by problems associated with converting a natural, undisturbed forest to a managed man-made forest. The highly mobile, often unstable physical environment, the wet, turbulent maritime climate, and the past lack of continuity of silvicultural management efforts make management in the Islands a challenge.

Mass wasting on the Queen Charlotte Islands is accelerating under current forest management practices (Rood 1985) and instability is expected to plague forest managers for the foreseeable future. While selected silvicultural practices may assist in maintaining some stability by not aggravating the natural system, normal climatic cycles will inevitably result in mass wasting events over which the land manager has no control. As Godwin (1968) noted:

"what we have to do is to learn to live with and manage the system between catastrophes [i.e., 50 year storm events]." Between the catastrophic events, however, are the regular storms with return periods of 1-5 years. These are known to cause mass wasting in clearcuts (Schwab 1983), and it is in response to them that this report is attempting to identify silvicultural solutions to mass wasting.

3 NATURAL VS MANAGED FORESTS

3.1 Biological Differences and Effects

Natural forests differ from managed forests in a number of clearly defined aspects, the degree of each difference being proportional to the level or intensity of management. The differences include:

Origin

The natural or old-growth forests of the Queen Charlotte Islands reflect a productive, although dynamic geologic and climatic environment. This is particularly apparent on unstable areas and areas exposed to storm winds, where distinct changes in forest type distinguish overmature from immature stands. The natural forest on these areas tends to be a mosaic of even-aged groups whose sizes reflect the type and severity of past disturbances. Observations indicate that major disturbances leading to successional interruptions occur with a frequency of 50-500 years. On the other hand, man-made forests in the Queen Charlotte Islands are even-aged (and essentially evenly spaced) over considerable areas, the result of harvesting plans which, at present, are dominated by progressive clearcuts.

Species and genetic composition

Man-made forests may consist of introduced species or provenances, with a relatively narrow genetic base within 1 year's planting. Where planting has not been carried out, harvested areas naturally regenerate to native species from either the seedbank of the previous crop or windborne seed from adjacent stands. Seed distribution in the Queen Charlotte Islands is good, with a natural seed "flow" dominated by prevailing wind patterns, predominantly west to east. Artificial regeneration by either planting or direct seeding can be used to reverse the natural flow, although this may result in off-site planting and future health and stability problems if carried out unwisely (Day 1950).

Inventory and management approach

The natural forest in the Queen Charlotte Islands is generally old and classified for current management purposes as "overmature". Old-growth stands often contain a number of distinct age classes, distributed directly in relation to canopy breakup (i.e., as one class develops, a later successional stage species regenerates beneath the overstorey). Other circumstances may interfere with this process. The introduction of deer, for example, has largely curtailed the successful re-establishment of western redcedar over large areas of the Queen Charlotte Islands (Pojar and Banner 1982; Coates et al. 1985). As well, regenerating understory crops can sometimes stagnate beneath an overstorey, or be inherently unstable because of the rooting medium, and thus fail to become part of the stand. Advance growth of this type cannot be considered for retention or "release" as a regeneration option, because of its poor ability to recover (shown by depressed crown development). Examples of this "false succession" can be found throughout the west side of the Queen Charlotte Islands, and are often located under a dense cover of young trees (60-90 years old) where the canopy has not yet become broken or stratified.

Age and size distribution of individual trees

Intensive stand tending in even-aged forests produces trees of uniform diameter and height, whereas natural stands, particularly on the west coast of the Queen Charlotte Islands, typically produce trees of widely differing size. As a result, both the machinery and techniques used for harvesting in the two different stand types differ radically. In old-growth stands, where it is uneconomic to yard small pieces of timber with machinery that has been designed to yard the largest pieces, large quantities of slash are left following the harvest. In contrast, because of the uniform and smaller pieces of timber within managed stands, smaller equipment can be used and significantly less slash is left following harvesting. The more compact equipment reduces the need for wide roads, and yarding the smaller timber produces less disturbance -- two factors

that reduce the impacts of forest harvesting on mass wasting. The reduction in slash also affects microclimate (e.g., less protection for regeneration) and site hydrology (e.g., precipitation interception and routing), and hence slope stability.

Hydrologic regime

The influence of silvicultural treatments on forest hydrology has been the subject of continuing study (Bishop and Stevens 1964; Swanston 1969; Chamberlin 1972; Swanston 1974; Swanson and Dyrness 1975; Harr 1976; O'Loughlin 1981; Bosch and Hewlett 1982). Hydrologic changes have been documented at both the watershed and site levels. Although changes at the watershed level (e.g., water yield, water quality, peak flow timing and size, and low flows) are important to resource managers, they are beyond the scope of this paper. Of greater relevance here are the hydrologic changes at the site level, which can affect slope stability. These include:

- changes in interception of precipitation and delivery of water to the soil surface
- snow accumulation and melt
- soil disturbance, root decay, and the resulting changes in the routing of soil water and reduction in soil shear strength
- changes in evapotranspiration.

The hydrologic changes to a site are dependent to a large degree on the silvicultural system. The most apparent and best studied relationship is that between harvesting and root decay (Bishop and Stevens 1964; Ziemer and Swanston 1977; Ziemer 1981). The clearcut silvicultural system removes all trees on a site. As roots decay over a 5- to 8-year period, slope shear strength declines, predisposing some sites to mass wasting. Maintaining a root web on a site requires that live trees be left standing. Hence, the closer that harvesting approaches the selection system, the more live roots and soil shear strength will remain.

Research results indicate that clearcutting can increase the rate of snowmelt during rain-on-snow events. Harr (1981) suggests that this rapid snowmelt and release of water to the soil can initiate mass wasting. Silvicultural systems that maintain a high proportion of the canopy intact will not alter snowmelt to the same extent as clearcutting. A relationship between forest harvesting, the movement of water in the soil, and slope stability has been suggested. Chamberlin (1972) hypothesizes that the stability of steep mountain soils is related to their ability to quickly drain large volumes of water without saturating the entire soil mass. He concludes that instability would follow forest harvesting if root disintegration caused long-term collapse of voids in the soil that had previously allowed rapid drainage. If this is the case, silvicultural systems or treatments that maintain the root system on a site would maintain soil drainage and hence slope stability. The links between forest harvesting, changes in interception of precipitation, delivery of water to the soil surface, evapotranspiration, and slope stability have not been clearly defined. It is probable that the greater the number of stems removed from a site, the greater the influence on hydrology, and the greater the effect on slope stability.

Health and susceptibility to attack by disease and insects

Both natural and man-made forests are prone to insect attack and disease. A knowledge of the insect and disease conditions in the natural forest is essential if silvicultural alternatives are to be recommended. Some alternatives are inappropriate because they expose regenerating stems to higher than acceptable risks. Of immediate concern is the presence of mistletoe (Arceuthobium spp.) in western hemlock on the Queen Charlotte Islands. Silvicultural systems that favour hemlock as an understorey crop are not appropriate if the canopy contains infected stems. Armillaria mellea, Fomes annosus, and Polyporus tomentosis are among the root rots known to be present in the Charlottes, but their extent has not been

defined. Further investigations will be necessary, not only for selecting alternative silvicultural systems, but for making prescriptions on stable sites.

Many insects are affecting the Island's forests. For example, although spruce aphid (Elatobium abietinum) is generally restricted to the coastline, it has presented a problem in recently thinned stands (R. Frank, pers. comm., 1984). Furthermore, black-headed budworm (Acleris gloverana) attacked approximately 28 000 ha in 1985, including regeneration on areas logged in the 1940's. It appears that aphid populations are enhanced by open canopy conditions, and this fact must be considered in thinning prescriptions, as well as in application of heavy crown thinnings in the shelterwood system (see Section 4.1.1).

Aside from these insect and disease considerations, the choice of silvicultural system for unstable sites is not anticipated to aggravate present problems (L. Unger, pers. comm., 1985, Can. For. Serv.).

Stocking levels

Stocking levels differ widely between natural and man-made forests. Overstocking which can produce major problems (such as fierce inter-root competition, snow press, and stagnation), can easily occur in made-made forests where planting is heavily supplemented with natural regeneration. It is more easily solved, however, because -- unlike trees in natural stands -- planted stock has size and genetic advantages. As well, individual tree size and distance between trees can be influenced by cultural practices such as thinning. Theoretically, a stand managed for slope protection should have controlled stocking to the point that the strength of the root web is maximized.

Aesthetics

The degree of aesthetic or visual difference between natural and man-made forests is highly dependent upon the silvicultural system. For example, clearcutting creates major visual differences from the natural

forest, while selection forests appear virtually undisturbed. This example illustrates the fundamental difference between the extremes of the silvicultural systems; selection systems maintain the forest influence -- both physically and visually -- whereas the clearcutting system removes the forest influence completely for a period of time. While the topic of aesthetics is beyond the scope of this paper, it is noteworthy that the application of alternative silvicultural systems to unstable sites will most likely enhance the visual resource.

3.2 Reaction to Physical Influences

Climatic forces, including wind and precipitation constitute a major source of physical pressures. Climate is highly variable and has been the subject of study for many years (e.g., Day 1957; Calder and Taylor 1968). Cycles vary from major changes taking many thousands (sometimes millions) of years, to seasonal influences and daily fluctuations of temperature and air movement.

Periodicity of climate significantly affects forest vegetation and its growth rates, with significant changes occurring over 30- to 35-year cycles (Ford and Deans 1978).

Wind and precipitation events follow these cycles. European foresters recognize "normal" gales (occuring annually), "abnormal" or severe storms (every 4-5 years), and "phenomenal" events (every 30-35 years) (Anderson 1954; James and Dier 1968). While climatic data have not been collected long enough to allow researchers to conclusively identify such cycles for the Charlottes, there is geomorphic and biologic evidence to suggest that such cycles do occur (J. Schwab, pers. comm., 1985).

It is important to recognize that destructive climatic cycles have a shorter return period than current stand rotations and that the probability of a particular event occurring must be considered in stand manipulation decisions. While the natural stand takes its chance under all events, the man-made forest, where stand treatment has been carried out and gaps have been created in the canopy, is extremely vulnerable

during periods of gale activity. This is a major factor to be considered when alternative silvicultural prescriptions for unstable sites are formulated. The silviculturist should understand the nature of climatic vagaries and plan treatments accordingly.

Contradictions abound as to what precautions should be taken to minimize the effects of gales, storms, and phenomenal events. For example, Saville (1983) suggests that thinned and unthinned stand edges are equally vulnerable to windthrow. While there are treatments that merit investigation in the Queen Charlotte Islands, there is no guarantee that windthrow can be totally eliminated from a managed stand.

4 TRADITIONAL SILVICULTURAL SYSTEMS

The application of traditional silvicultural systems produces either even-aged or uneven-aged stands.

4.1 Even-Aged Stands

In theory, an even-aged forest stand contains trees all the same age, although, in practical terms, there is generally an age spread of up to 20% of the "rotation" age. The rotation age, in this instance, is applied to managed stands of ages less than 120 years. In the Queen Charlotte Islands, for example, where under true intensive management rotation may be 50-75 years on good sites, the age spread of even-aged stands would be very narrow. Where the stand age exceeds 120 years, it is rare to find a truly even-aged stand because canopy breakup is generally advanced and a conifer understorey is present. Caution must be exercised, however, in assessing whether or not a stand is even-aged. A two canopy layer forest must not automatically be classified as uneven-aged. Several species may regenerate at one time, with the later successional species remaining in the understorey, awaiting canopy breakup of the early successional species. At lower elevations in the Queen Charlotte Islands, this situation frequently occurs where slide areas have been colonized by red alder, Sitka spruce, western redcedar, and western hemlock. The red alder immediately express dominance (in some instances associated with Sitka spruce), while the conifers constitute a secondary canopy layer that will "release" when the red alder becomes decadent between the age of 40 - 80 years. This process varies according to seed source, aspect, elevation, and ecosystem unit.

Even-aged stands are produced by three traditional silvicultural systems: clearcutting, seed tree systems, and shelterwood. Clearcutting is essentially the only silvicultural system presently used on the Queen Charlotte Islands, and although there are many reasons for using this system (such as economics), it is not always appropriate for unstable

sites (Troup 1952). The seed tree system, essentially a variation on the clearcutting system, is not considered a viable alternative because of seed tree windthrow. The shelterwood system is more promising as a method of establishing even-aged stands on unstable sites.

4.1.1 Shelterwood system

In a shelterwood system the existing stand is used to regenerate and protect the young trees of the next tree crop. The system is based on a three-stage operation: the stand is prepared by a light, partial cut to correct unfavourable stand conditions; a seed cut is made to permit germination and establishment of the new crop; and overstorey is removed such that the remainder of the previous crop is cut to expose the newly regenerated trees.

There are a number of features of the shelterwood system that make it attractive for application on unstable sites in the Queen Charlotte Islands. Throughout the shelterwood operation, for instance a continuous root web is maintained, particularly in intensively managed, even-aged monocultures where considerable root grafting has occurred. The level of root grafting attained in a truly managed stand (where silvicultural operations have been continuously applied throughout the life of the stand) may, in the opinion of the senior author, exceed 90% of the stems by the end of the preparation cutting sequence. Thus, as trees are removed during the harvesting passes, the root web will commence to duplicate the old system. By the time the final removal cut is carried out and the old root system dies, the new crop will have a completely overlapping root web, and assume the stabilizing role of the previous crop.

Another advantage of the shelterwood system is that the canopy is rarely broken enough to significantly affect site hydrology (i.e., interception of snow and rain, snowmelt, routing of water to the soil, and movement of water through the soil) (Ford and Deans 1978).

There are also some disadvantages of applying the shelterwood system in the Queen Charlotte Islands:

- With a the lack of previous treatment, stands are not prepared for regeneration by this method.
- The native species exhibit inherent instability when the general canopy is suddenly opened.
- Characteristics of the physical system (Section 3.2).

Furthermore, in all multiple entry harvesting systems the native conifers are susceptible to the entry of disease following mechanical injury. This is not however, an insurmountable problem and can be solved with the use of shields to protect residual stems.

Although examples of naturally occurring group shelterwood are found in both the Rennell Sound and Deena River areas, the only variation of the shelterwood system that, in the senior author's opinion, has potential application in the Queen Charlotte Islands is an adaptation of Wagner's shelterwood system (Troup 1952).

4.2 Uneven-Aged Stands

Uneven-aged stands are typified by either major age class groupings (examples in the Queen Charlotte Islands can be found in the Bonanza Creek area) or an evenly distributed age spread (no examples found). It is rare to find the latter occurring naturally in forests of the Pacific Northwest because of natural successional processes and the cycles of natural catastrophic events. The origin of major age class groupings in uneven-aged stands can be traced to wind storms (not necessarily associated with precipitation) where individual large trees, or small groups of large trees, have been blown over. Because "wind events" causing this type of spot damage can occur annually, theoretically it should be possible to find naturally occurring stands exhibiting single tree selection characteristics. However, major "wind events", coupled with high levels of precipitation, can be so devastating that situations where single trees have blown down tend to be masked. The return period

of such major wind/precipitation events, as noted by Wilford and Schwab (1982), has not been determined because of insufficient data.

The traditional silvicultural systems used to produce uneven-aged stands are the selection system, and variations of the group selection system.

4.2.1 Selection system

The term "selection system" has been loosely defined in the past. Types of selection systems vary from pure, single tree selection systems as applied in France, Germany, and Switzerland (in which single trees are removed as they reach a specified diameter), to diameter limit operations (often called "high grading") as practised in parts of British Columbia, particularly the Interior.

Single tree selection systems are difficult and expensive to apply, and often produce a shift to shade-tolerant species. There is no "rotation" as such. Trees scheduled for harvesting are selected on the basis of diameter size and position in the stand and fellings are evenly spread over the entire cutting unit. Ages within the stand vary from newly regenerated germinants, to the age at which the diameter criteria for harvesting are attained. There is a generally accepted relationship between the number of trees in each diameter class throughout the entire stand (Meyer 1953). Fellings are therefore also scheduled in a range of diameter classes to ensure the "continuum" of the system.

The prime advantage of a true, single tree selection system is the continuing protection afforded the site in terms of both aesthetic and site stability values. Protection in terms of fire hazard reduction is debatable, (particularly in the Queen Charlotte Islands), as opinions vary as to the merits of an uneven-aged stand over an even-aged stand in reducing fire hazard.

Selective logging attempted in Alaska in the 1930's was generally unsuccessful, resulting in badly damaged residuals,

extensive blowdown, and poor growth of regenerating understorey. Furthermore, it was expensive (Anderson 1954). Blowdown of residuals on steep slopes aggravated mass wasting, and thus selective logging practices, although recommended by Phillips (1938), were only used to harvest cedar poles by crawler tractor on lower slope areas.

Direct application of single tree selection to natural, old-growth stands in the Queen Charlotte Islands would be very difficult. Constraints exist because of the present age class structure, characteristics of the native and desired species relative to seedbed requirements, lack of expertise available, and the road maintenance needed for continuing access. It should be noted that no examples of naturally occurring selection systems were found by the authors during field work. Practical options of single tree selection are discussed in Section 7.

4.2.2 Group selection (uneven-aged groups)

In group selection, a modification of single tree selection, small groups of trees are removed during harvesting "entries". Designed to produce a grouped, all-aged stand, group selection widens the number of species that can be successfully regenerated (compared to single tree selection), and overcomes a number of operational disadvantages. For example, thin-barked species such as western hemlock and Sitka spruce are highly susceptible to fungal infections (particularly Fomes annosus) following mechanical injury. Removing groups, rather than single trees, confines damage to access routes into areas under treatment. Furthermore, the site can receive greater cultivation -- a distinct advantage in regenerating Sitka spruce. Research and experience will indicate the trade-off between seedbed preparation and site disturbance leading to slope failures. The size of group treated is a management decision based on the diameter range that can be marketed, the silvical characteristics of the species desired for regeneration, the cutting regime for the

unit, and the nature of the instability of the site. Periods between stand entries in group selection systems are generally longer than for single tree selection. Intermediate cuts in lower diameter classes are still required to maintain size class balance.

While single tree selection would produce an almost pure stand of western hemlock in the Queen Charlotte Islands, group selection could be used to regenerate an element of Sitka spruce. Stand treatment in the form of numerous intermediate cuts would be required to ensure survival of the spruce. Because of the favourable wildlife conditions created and the difficulty in hunting caused by restricted "within-stand" sighting, western redcedar would not likely be present.

4.3 Discussion of Traditional Silvicultural Systems

The shelterwood and selection silvicultural systems have been applied successfully in many parts of the world, and given sufficient time and management, variations of the two could be used to maintain slope stability in the Queen Charlotte Islands. Some constraints (see Section 5) would severely restrict their use, but protection values may be such that the costs of implementation would prove worthwhile.

Clearly defined objectives and long-term management intent are prerequisites to successful implementation of any of these systems. For example, conversion of the existing old-growth forest to an uneven-aged group selection would take at least 100 years, although protection benefits would be realized well before that time had elapsed, probably from about year 40 onwards.

5 CONSTRAINTS ON DIRECT APPLICATION OF TRADITIONAL SILVICULTURAL SYSTEMS

5.1 Management

To date, unstable sites on the Queen Charlotte Islands have been treated in one of three ways: clearcut harvested; deferred temporarily from harvesting; or designated as environmental protection areas and removed from the annual allowable cut (AAC) calculation. Consideration of alternative silvicultural systems will affect each of these management treatments in different ways.

Of all the systems, the clearcut silvicultural system is the simplest with which to administer an area and the most economical for producing a given volume of wood. The overall economic impact of its use in a specific harvesting operation will depend on the extent of the area that is being managed under a different silvicultural system. A consideration in selecting an alternative silvicultural system is the cost associated with not changing (i.e., the impacts to the forest land base and fisheries resource as a result of clearcut-related mass wasting). Direct harvesting and rehabilitation costs are one aspect; the other is the need for a continuity of management intent and field expertise.

Alternative silvicultural systems may prove to be the only way that harvesting will be allowed on "temporarily deferred areas". If this is the case, use of these systems will enable the full harvest of the AAC in the operating area.

Successful results from the application of alternative silvicultural systems could lead to a re-evalutation of Environmental Protection Areas and an increase in the AAC. As with most economic commodities, the marginal increment of production will be more expensive, but availability will improve.

Virtually any silvicultural system introduced would be more expensive to apply than the present clearcutting system, particularly considered in light of converting the natural forest to managed second growth stands. Given the size and frequency of climatic events that generate mass wasting

events on the Charlottes, there is no guarantee that any alternative system would be more than marginally better than the existing system. Gains might be made in root web strength if the present clearcuts were modified to strip shelterwood, and this is one possibility that should be explored in the conversion (from natural to man-made forest) process (see Section 7).

The forest industry in the Queen Charlotte Islands works, as in other parts of the province, to cutting quotas and marketing priorities. As noted previously, clearcutting is the most administratively efficient means of meeting volume regulation. Management plans are simple and all management activities, including cruising, engineering, harvesting, and reforestation, are straightforward. Also, road lengths are minimized, and active logging and silvicultural work can be directed to specific areas.

A major constraint on applying alternative silvicultural systems is the lack of available expertise -- from the operator who harvests the produce and the field foreman who marks and supervises the operation, to the silviculturist who prescribes the activity and the forest manager who authorizes the plan and understands the complex interaction between silviculture and the physical and biological functions of a site. Because of the long-term nature of tree growth, considerable time is required to gain such expertise, particularly in combination with local knowledge. Thus, to apply alternative silvicultural systems on the Queen Charlotte Islands, many preliminary steps must be taken, all of which require planning, firm goals, expertise, resources for effective implementation, and the political will to carry plans to fruition.

5.2 Biological

The natural forests of the Queen Charlotte Islands are generally overmature. Not only is the regenerative ability of the existing, desirable phenotypes suspect, but reliance on natural regeneration excludes introduction of improved genotypes. Decadent climax forests in the Islands are poor candidates for any other system except total removal and replacement, unless the system includes an element of planting.

Native tree species impose constraints by their very characteristics. For example, all conifer species in the Queen Charlotte Islands are shallow rooting, and opening the canopy would increase tree rocking and blowdown, both of which have been linked to mass wasting. (Tree rocking focuses pressure and leads to dynamic loading of slopes [Swanston 1969]). Because of these hazards on unstable slopes, crowns require continual thinning throughout the life of the stand to maintain stable configuration. With commercial thinning, logs should be lifted clear of the ground to protect surface rooting systems and prevent damage to crop trees. As well, although native tree species are generally shade tolerant shade does depress growth rates, and thus any regeneration system using partial shade would lengthen rotation (Harris 1974).

Deer have been introduced several times to the Queen Charlotte Islands (Pojar and Banner 1982), and numbers have increased significantly because of the lack of predators and the presence of an abundant food supply. These animals constitute a major constraint on any silvicultural system that uses natural regeneration below an existing canopy. Such systems provide highly favourable habitat for deer, and would undoubtedly aggravate an already difficult situation, particularly if western redcedar (a preferred browse species) were present. Use of chemical repellents on a sufficient scale to be effective would be prohibitively expensive (Sullivan et al. 1983); and the introduction of predators to control the deer has, for the time being, been vetoed by the local residents.

Some control would be achieved if large areas of very dense Sitka spruce were grown and understorey vegetation totally eliminated by heavy shade. However, because of the nature of stand tending in intensive management of second growth, where the canopy is opened on numerous occasions, this is not considered a viable population control option, nor is it compatible with enhancing stand wind firmness.

Currently then, the presence of deer has to be accepted as a major silvicultural constraint on growing an uneven-aged forest stand. If deer populations are to be maintained at present levels, management practices and expectations will have to be modified to accommodate them.

5.3 Physical

The climate dominates physical processes in the Queen Charlotte Islands, and any silvicultural systems relying on partial cuts must be modified to accommodate the extremes of both wind and precipitation. The traditional systems described in Section 4 were developed under very different physical (particularly climatic) circumstances, than those found in the Queen Charlotte Islands. Wind in Europe is a continuing influence and modifies tree form from an early age. Even with stand canopy modification, catastrophic wind events create havoc at regular intervals throughout Europe (Godwin 1968). On the steep slopes of Central Europe, protection forests are managed for snow avalanches rather than mass wasting. A system developed to hold or modify snow movement is not necessarily adaptable to earth and debris movements. Furthermore, Swiss protection forests are often combined with engineering structures to stabilize snow movement, an option not being considered for mass wasting in the Queen Charlotte Islands.

A hydrologic consideration is the influence of canopy configuration on precipitation interception patterns (Bull and Reynolds 1968). Reducing canopy area reduces interception (Ford and Deans 1978), shortening the time from the onset of precipitation to soil saturation and unstable sub-surface conditions. The selection and shelterwood systems reduce the canopy area, but not as significantly as clearcutting does. Thus, while these alternative systems may have less hydrologic impact on a site, the effect may be negligible if the net result of partial cutting is increased blowdown and dynamic loading (see Section 9).

Of major importance to forest managers is the size of material to be removed in partial cutting operations. Physically moving old-growth trees (in sizes required for processing) requires large, expensive equipment. Machinery used in Europe to harvest produce from selection and shelterwood systems is small in comparison to equipment required to move produce from the natural forests of the Queen Charlotte Islands. Moreover, material felled in true protection forests in avalanche control areas of Central

Europe is often left on the ground or removed by hand for fuelwood. Cutting trees and leaving them on the ground is one manner in which stands on unstable sites in the Charlottes could be developed into uneven-aged stands. Removing subsequent smaller trees with smaller scale equipment would be possible in 20-40 years.

5.4 Summary of Constraints

Many of the biological and management constraints described above can be overcome with time and management intent, and are thus possibly short-term. On the other hand, constraints imposed by climate and soils will continue, so that any alternative system selected for implementation must be modified to accommodate the climatic conditions of the Queen Charlotte Islands.

The managed forest may be far more vulnerable to severe climatic events than the natural, undisturbed forest. Reasons include: the accelerated nature of growth and successional processes because of intensive management practices such as improved genetic introductions and fertilization; canopy disruption from stand treatment entries; and damage to residuals during harvesting operations, particularly root damage, entry of disease, and loss of stability.

Traditional silvicultural systems, however, do have potential use for the management of unstable sites, and selected features of these systems could be applied to good effect (Section 7).

6 CURRENT SILVICULTURAL PRACTICES

Progressive clearcutting is used almost exclusively in all harvesting operations on the Queen Charlotte Islands. Over the last 10 years there has been a fairly consistant annual harvest of 3000 ha. At present, leave strips are not a standard prescription because of past experience with blowdown. On occasion, protective strips of timber are left if windfirm boundaries can be located.

For the most part, site preparation is not required for successful regeneration on the Charlottes. Over the past 5 years prescribed burns have been tried with positive results where burns have achieved ignition. The burning program will continue in the future, but will involve only a small percent of harvested areas.

The majority of clearcut areas regenerate naturally to western hemlock and Sitka spruce. Approximately 28% of harvested areas are planted to Sitka spruce. There are two reasons for the planting program: first, to ensure a high component of spruce, second, to ensure more rapid establishment on brush sites.

The brush management program focuses on red alder -- the primary competitor to conifers. Present efforts have concentrated primarily on older backlog alder areas (15-25 years old). Alder at this age tends to have densities of 1500 or more stems per hectare and severely suppresses the understorey of conifers. Over the past 5 years an average of 1500-2000 ha per year have been treated by girdling or chemical hack-and-squirt. Both techniques have been used in approximately equal proportions, but there is now a growing trend to more girdling. At the present rate of treatment, it is anticipated that within 5 years the backlog alder should be well under control, at which point the brush management program will shift to treating recently harvested sites (i.e., within 3-5 years of harvesting). Alder control is restricted to valley bottoms and lower slopes. At present, alder is left on unstable sites and landslide tracks.

Juvenile spacing is conducted for stocking control and to increase the spruce component. The level of spacing is expected to increase to a level of

700-800 ha per year by 1988 and be maintained at 1000 ha per year to keep current with the need. The senior author's experience in other areas indicates that an appropriate juvenile and commercial thinning program should be in the order of 5000 ha per year, given the annual harvest of 3000 ha in the Queen Charlotte Islands.

Clearcutting is an effective silvicultural system for the majority of sites in the Queen Charlotte Islands. It is desirable economically for harvesting, and provides flexibility in location of windfirm boundaries. It does not, however, ensure the maintenance of the root web or forest influence on unstable sites.

7 SILVICULTURAL OPTIONS

7.1 Leave As Is

The simplest "solution" is to leave the present system alone and merely improve current silviculture and harvesting practices and techniques. Research suggestions for improving silviculture relative to slope stability are presented in Section 9. Improvements to forest harvesting have been described by Krag et al. (1985).

There are several silvicultural aspects of the present clearcutting operations that could be addressed within current management plans. For example, setting boundaries could be aligned using the prescriptions proposed by Hutte (1968). This is being done to a limited extent, but the natural forest is not totally co-operative in this respect and fringe blowdown will always pose a problem (see Section 9). Furthermore, time of felling has not been isolated as a factor in root web strength deterioration, and there are research opportunities in this area to determine whether spring felling operations (during the bark peeling stage) influence instability within clearcuts.

Modifications to reforestation practices may provide enhanced slope stability. Although planting in advance of clearcutting has been unsuccessfully attempted in Europe (Ford 1978), underplanting is again being carried out in selected stands in northern Germany. This practice warrants investigation, possibly using seed instead of seedlings. In addition, stock trials are recommended to ascertain whether or not re-establishment of the root web can be accelerated (see Section 9).

The clearcutting silvicultural system is economically acceptable to the forest industry. Modifications, even at considerable expense, may be more acceptable than the introduction of an alternative silvicultural system, which, although potentially costing less, would require a major change of attitude and retraining.

A final note on the "leaving as is" option. Experience in Europe shows that managed stands are not as physically stable as old-growth

stands (Saville 1983). The situation can be improved with stand tending throughout the rotation. Without tending, the existing physical stability problems such as blowdown would be minor compared to those that would likely result from inadequately managed second-growth stands. The implications for mass wasting are significant.

7.2 Modify Systems in Current Use

A number of modifications are possible within current practice, mainly related to cutting patterns and treatment of fringe zones. Fringe blowdown is a feature of harvesting operations in the Queen Charlotte Islands, and even with careful setting boundary alignment, windthrow will, in all likelihood, occur.

Progressively clearcutting strips against the general prevailing winds would permit fringe blowdown to be picked up in subsequent operations. It would also provide a height gradient to ease wind over the crowns of the developing crop (Troup 1952; Ruth and Harris 1979). However, it would not solve the problem of large root masses being poised on steep slopes following blowdown and further loosened during recovery operations. This hazard could be partially overcome by tailoring yarding systems so that they inhibit downward movement of large stumps (e.g., yarding uphill) or by leaving a proportion of blown-down trees within the blowdown fringe. In the latter case a high proportion of waste would have to be accepted.

Setting boundaries should not run directly uphill in a straight line, but be staggered in a configuration resembling the cutting edge of a ripping saw. Indentations should be carried approximately one tree height into the residual stand and the line run diagonally across the slope of the hill to permit harvesting of all felled material in the indentations. Gullies and small streams on steep slopes should not be used as setting boundaries.

All small trees, regardless of size, should be felled and not left for knockdown during yarding operations. A modification of this system would be to "clean" the adjacent strip (scheduled for the next harvesting pass) by felling and bucking up all small unmerchantable trees. This treatment would hasten the decomposition process of the small slash, and provide additional light at the forest floor for advance regeneration. It would serve a similar purpose to a preparatory cut in a shelterwood system. While slash decomposition proceeds rapidly in the Queen Charlotte Islands, total removal of the canopy would generally slow micro-organism processes (Odum 1971; Hendrickson et al. 1985) compared to those under a closed canopy. Whether this system would provide benefits in the form of rapid site regeneration following clearcutting requires investigation (see Section 9). Pre-planting operations could be carried out at this stage with rapid root growth plants (e.g., willow) if the presence of such vegetation was not expected to inhibit the growth of the next crop or encourage increased numbers of deer.

The "rip-saw" edge could be further modified by thinning to provide a shelterwood effect in areas that would be progressively clearcut. All the tallest trees could be removed in the thinned area, producing a tapered canopy configuration. This method of treating the edge might produce problems of dysgenic selection (a deterioration of genetic vigour over time) if natural regeneration was to be used to regenerate the next crop, although in the authors' opinion, this would not be a major problem. The thinned edge would project approximately one-half tree height into the residual crop, permitting removal of the largest trees without yarding through residual trees, although damage would undoubtedly be sustained by some of the smaller residuals in the thinned area.

A number of recommendations regarding the location of cutting boundaries in old-growth forests have been made (Ruth and Harris 1979; Rollerson 1980; Wilford and Schwab 1982) and include:

- Avoiding V-shaped configurations to prevent funneling wind.
- Shield susceptible fringes and shallow-rooted trees.
- Minimize the length of cutting boundary per unit area of setting where patch cuttings are prescribed.
- Do not prune edge trees, as it has been shown to have little value (Ford 1978; Saville 1983).
- Identify steep sites with shallow soils before harvesting and avoid setting boundaries on such sites.
- Use progressive clearcuts into the prevailing wind to encourage "stepped" regeneration that will deflect wind over previous cutover areas, and enhance future stand stability.

Recommendations for improving the stability of future cutting boundaries in managed stands include:

- Develop windfirm borders by initially cutting a strip to the windward of the projected cutblock, thus stimulating residual border trees to strengthen their root systems (Troup 1952).
- Thin and prune the area that will be a future stand edge, thereby preparing the area for exposure (Saville 1983).

7.3 Using Adaptations of Alternative Traditional Systems

As noted in Section 4, modified forms of alternative traditional silvicultural systems might be used where non-timber values are sufficiently high to warrant the cost of implementation. Possible adaptations include modified shelterwood, single tree, and group selection systems (either even- or uneven-aged).

Selection systems could be used in such areas as the shore of Rennell Sound where the present structure of young second-growth stands is suitable for initiating the first steps of the selection system process. The type of system, and hence the type of stand preparatory work, would reflect the species desired for regeneration. For example, there is little problem in obtaining natural regeneration of western hemlock because it tolerates a wide range of seedbed conditions (from highly

organic to mineral soil), and can regenerate under dense shade. It could, therefore, be regenerated relatively easily under single tree or small group selection, or any variety of shelterwood. Constraints arise with the presence of mistletoe or the entry of disease following mechanical injury during harvesting.

Western hemlock requires considerable tending, for although it regenerates freely and tolerates dense shade, young, densely regenerated stands suffer problems of stagnation and snow press, and stocking control is required at an early age (see Section 8). Careful control of stocking is required on a continuing basis to maintain the optimum space requirement for each tree according to its diameter at breast height (dbh). Each unit area of the stand can hold only a specific number of stems in each diameter class (the number in each diameter class reflects size and the time considered necessary to attain that size), as specified by the prescribed regime to achieve management objectives. For example, if the stand was to be managed solely for protection purposes, then the maximum specified size of the largest trees might be 20 m in height and 30 cm dbh. To obtain this size, a specific number of stems would be required in each 5-cm diameter class per unit area at any one time. Thus, the prescription to maintain a single tree selection system, with cutting cycles of about 5 years, might read:

dbh (cm)	no. stems/ha*	no. stems/ha**
5	150	1280
10	115	540
15	88	320
20	68	160
25	52	80
30	40	40

*Using a q value (or multipling factor) of 1.3.

**Using a q value of 2.0 (Meyer 1953).

The figures given above provide an example only: diameter classes and stems per hectare are determined according to the management objectives of the stand being treated. The number of stems per hectare for each diameter class is kept generally constant over time. Regulation and control under uneven-aged management are discussed by Troup (1952), Meyer (1953), and Alexander and Edminster (1977).

In addition to stand tending to maintain stocking levels, treatment would be required to keep the stand free of root rot, particularly Fomes annosus.

Clearly, applying the single tree selection system to maintain an all-aged stand of western hemlock would require intensive, continuing stand treatment. It is unlikely that produce, other than material felled directly onto a road, would be recovered, as the risk of stem injury to the residuals (and subsequent disease problems) during yarding operations would be too great.

Sitka spruce could not be used in this system because of its seedbed and light requirements. However, in place of single trees, groups could be removed, creating sufficiently large canopy openings to permit Sitka spruce to germinate and thrive. Some form of cultivation would be required and this would have to be done in such a manner that would not destabilize the site. Stocking levels would have to be maintained at a considerably lower level than hemlock. An example of a prescription for Sitka spruce group selection might read:

dbh (cm)	no. stems/ha (Ss)	no. stems/ha (Hw)
5	200	1000
10	100	600
15	80	100
20	60	20
25	40	10
30	25	5

Constant attention (at 5-year cutting cycles) would be required to maintain such stocking levels, and the material felled would have to be bucked up to allow rapid decomposition and permit access for future stand tending operations.

The examples noted above are hypothetical and would have to be modified to meet specific soil protection requirements. The stocking levels used reflect research observations noted in Section 3.

Application of strip shelterwood requires a different approach. Although produce would be realized, great care would be required to protect the regenerating trees and windthrow would be a constant risk. Similar constraints to species selection would apply. A series of preparatory cuts (or stock control operations fulfilling the same function) would be required, with the seed and removal cuts blending into a series of entries over a relatively short period (e.g., three entries 5 years apart). This system could be used to maintain a thrifty root web in sensitive steep slope areas (where risk of windthrow was low), in place of a progressive clearcut. However, no candidate stands suitable for treatment were identified during field inspections, and the modified clearcut would have to be used until such time that younger stands were grown to required specifications.

Information on root egress and growth of native conifer tree species grown under the foregoing systems in the Queen Charlotte Islands is unavailable. This aspect of stand management is noted in Section 9.

8 ASSOCIATED SILVICULTURAL CONCERNS

Silviculture requires a continuity of locally experienced staff, funding, research, and management intent. This need increases significantly with the application of alternative silvicultural systems. At present on the Queen Charlotte Islands there is a high turnover of silviculturists both in the Forest Service and in the forest industry. Silvicultural funding has been cyclical, however FRDA should provide the necessary funds to overcome the backlog. FRDA may also provide the necessary profile needed to establish and maintain management intent. Silvicultural research has been limited on the Charlottes and must be increased to provide sound advice on many aspects of alternative silvicultural systems and techniques. Field silviculturists should be involved in the research effort so they can successfully apply the results.

The successful completion of backlog projects is seen as significant in two respects. First, it will indicate that there has been serious and continued display of intent on the part of forest managers. Second, it will provide the field silviculturists the time to fully explore the possible silvicultural alternatives for managing unstable sites.

Permanent, stable access is required throughout the forest if intensive silvicultural practices are to be carried out. A large investment has been made in forest roads, much of it of doubtful long-term value. Unless access is assured, it is unlikely that second-growth stands will receive sufficient attention. As noted earlier, man-made second-growth stands are generally more prone to problems than natural, undisturbed areas. Contingency management will assume a higher profile in the foreseeable future, and high quality access will be a prerequisite to salvage and stand treatment operations.

The role of roots in maintaining slope stability has been thoroughly discussed in the literature. However, the focus has been on the decay of roots following logging, with little recognition given to the effect of the elimination of the shrub layer when canopy closure develops in a plantation between the age of 15 and 40 years. While the root web of the trees is generally anticipated to provide adequate soil shear strength, the implications of the loss of the shrub layer root system are not clear.

9 RESEARCH OPPORTUNITIES

There are both short-term (1 - 10 years) and long-term (10+ years) silvicultural research opportunities for unstable sites in the Queen Charlotte Islands.

9.1 Short-Term Studies

- Research to determine whether there is a correlation between time of felling and numbers of "within clearcut" failures is required. Although root web failure has been investigated (Ziemer 1981), little research has been carried out on the influence of felling time during the year and the loss of gripping ability between root and bark. Bark peels easily during the early part of the growing season, and possibly the component of soil shear strength created by roots is affected in a similar manner.
- Studies of the rate of root egress and related root web strength characteristics are required. The period necessary for second-growth roots to assume the stability role of the former crop is not known. Research should address natural regeneration of single species and mixtures, focussing on soil properties and soil moisture status, as well as on a variety of planting stock, spacing, and planting techniques. Further to this area of study, the role of root grafting and root "overlap" require investigation.
- Quantification of the degree of disease hazard in stands, and prescriptions to counter the problem are required. Stand tending operations create potential disease hazards by root-to-root contact. If disease is introduced to a stand there will be an overall reduction in the ability of the stand to provide shear strength to the soil.

- Planting and stock trials are required to study a variety of spacings, mixtures, stock, and stock treatments involving various growth stimulants to promote root growth.
- Planting trials are required to determine optimum boundary configurations, treatment of understorey prior to harvesting, pre-planting trials, and "feather" edge cuttings (tapered density clearcut edges).
- Stock trials to monitor the effect of different tree species and the influence of cultivation on slope stability are required.

9.2 Long-Term Studies

- A series of demonstration areas are required to show the result of selected silvicultural practices. These areas should include examples of: the application of traditional silvicultural systems (group and single tree selection), pre-treatment of understorey, setting boundary alignment, streamside and ridge top protection forests, and introduced species. In addition, such demonstration sites could be used as sites for continuing slope stability investigations. This work would also provide information on costs of each silvicultural technique.
- Long-term spacing trials are required to determine the effect of growth rates, optimum stocking levels, and species mix on root web growth and slope stability.
- Matched thinning plots are required to determine the influence of climate on stand behaviour. Such research should include investigations into plantation edge stability and effects of pruning on wind patterns and turbulence within the stand canopy.
- Investigation of the role of alder in affecting silviculture management is required. Studies should focus on the influence of alder on root web re-establishment, hydrologic regimes at a site, and site enrichment, as well as on its value as a nurse crop. The investigation should include both unstable sites and sites on which slope failures have occurred.

Long-term silvicultural research is subject to severe constraints of management intent and funding. Given the extent and significance of mass wasting/resource management problems on the Queen Charlotte Islands, it is assumed that if long-term silvicultural projects are initiated, the Steering Committee of the Fish/Forestry Interaction Program will ensure the projects are adequately funded to completion.

10 DISCUSSION

The forests of the Queen Charlotte Islands are dynamic, vigorous, and have the potential to out-produce most other areas of the Pacific Northwest.

Forests of the Islands are subjected to a number of constraining influences that narrow the range of silvicultural treatments associated with alternative traditional systems. Within the limits of those constraints, a degree of soil protection can be realized. Implementation of alternative systems or techniques will lead to higher logging and administrative costs. The costs will be proportional to the extent of forest land requiring alternative silviculture for slope stability purposes. In most cases, the total area will not be a significant proportion of an operating area.

So that alternatives are fully understood, differences between natural and managed forests must be appreciated. When a forest comes under intensive management, the structure and function of the forest ecosystem are altered, and, although the basic principles of silviculture have been derived from natural processes, the natural forest does not necessarily provide a good example of intensive silvicultural practice. Thus, while examples of a true selection system cannot be found in the Queen Charlotte Islands, the system should not be excluded as a management option, provided the forest manager is prepared to be committed totally to implementing the selected silvicultural system over a prolonged period.

As noted in Section 8, an essential component of continued, intensive silvicultural management is a permanent, stable road system. However, the roads required for silvicultural operations do not have to be of the standard required for present logging equipment. Where long reach yarding systems have minimized logging road length, a supplementary road system (suitable for crewcab and crummy access) could be constructed through large unroaded settings some 10-15 years after the completion of harvesting operations. In this manner, impacts of roading would be spread over time, with secondary roading having minimal influence on slope stability, streamflow regimes, and water quality.

A number of constraints have been outlined, including both physical (as related to climatic influences) and biological (as related to the silvical characteristics of native coniferous tree species). One major constraint, the presence of deer, was briefly discussed, but no solutions or research opportunities offered.

Current silvicultural practices and the options available to forest managers were briefly reviewed. Opinion differs about what is the precise impact of removing forest cover, but it is suggested that if forest engineering practices are changed (as per Krag et al. [1985], for example) the number of slope failures within clearcuts would be reduced significantly.

Modification of current practices is suggested, centred mainly on alignment and treatment of fringe zones and setting boundaries. None of the suggested modifications would totally eliminate within-clearcut slope failures: regardless of the action taken, little can be done to counter major climatic events. These are of such magnitude in the Queen Charlotte Islands that any forest system, no matter how well tended, is vulnerable to mass wasting.

At present, a concerted effort is being made to address the silvicultural backlog. Action in this respect may very well signal the beginning of the administrative commitment required to apply sound silvicultural techniques to slope stability problems.

Research opportunities of both short- and long-term duration have been outlined here. In addition to research by the B.C. Ministry of Forests, it is suggested that a co-ordinated program of local research be undertaken by both the resident companies and the B.C. Ministry of Forests. The program should be outlined by a group of local silviculturists in co-operation with Ministry of Forests personnel.

The forests of the Queen Charlotte Islands present a formidable challenge to silviculturists. The region's potential for rapid forest growth, together with highly sensitive non-timber values and an inherently unstable physical environment, create a dynamic situation that requires a variety of skills, a good working knowledge of silvicultural principles, sound judgement, and familiarity with local conditions. This preliminary appraisal has covered a few of the ground rules and outlined a variety of options available to silviculturists and forest managers.

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